PREDICTION OF PERFORMANCE IN SIGNAL DETECTION

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THESIS

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ABSTRACT

The performance of an individual in a signal-detection task depends on two independent psychological processes. One of these processes is sensory activation, and the other is cognitive decision. In a signal-detection experiment, a subject must decide whether a signal is present in a background of noise. When detection is not easy, the subject often shows bias. This thesis reports a signal-detection experiment that was performed (a) to determine the reliability of estimated individual bias parameters in a number of signal-detection tasks and (b) to evaluate the usefulness of estimates of individual bias parameters obtained in one signal-detection task for predicting performance in other signal-detection tasks having different signal-to-noise ratios. The signal-detection tasks required identification of two upper-case letters of the alphabet presented for brief fixed-time intervals. The letters were F (noise) and E (signal plus noise). Nineteen subjects participated in the experiment. The results supported hypothesis (a) inasmuch as estimates of individual bias parameters tended to be reliable. Performance prediction from one signal-detection task to another generally provided confirmation of hypothesis (b) as well. The support for neither hypothesis was very strong, however, and the thesis concludes with a number of suggestions for further research.

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I. INTRODUCTION AND BACKGROUND

The theory of signal-detection was initially developed in the years 1952-1954 by Peterson, Birdsall, and Fox at the University of Michigan and by Van Meter and Middleton at the Massachusetts Institute of Technology. At the same time, Smith and Wilson (1953) at the Massachusetts Institute of Technology and Muson and Kartin (1956) at Bell Telephone Laboratories were conducting psychoacoustic experiments that demonstrated the relevance of the theory to human observers. Meanwhile, Tanner and Swets (1954) were making a formal application of signal-detection theory to the field of vision.

Development of signal-detection theory has lead to a renewed interest in the possible processes involved in perception, psychophysics, and recognition memory. Recently, there has been a growing interest in various non-parametric analyses of detection/recognition experiments. Generally, in application studies, the experimenter's concern is whether a given performance change represents a change in sensory capacity or a change in a subject's (S's) criterion or response bias (Blough, 1957; Clark, 1966).

The fundamental problem in signal-detection theory requires that one of two stimuli, noise (N) alone or signal plus noise (SN), be presented on each trial. The Ss are required to say 'yes' if they perceive SN and 'no' if they

perceive N. Detection is difficult. After giving a response, the Ss are given feedback as to the correct answer.

If S_1 denotes an occurrence of SN and S_2 denotes an occurrence of N, then, by definition, $P(S_1)$ is the probability of a signal and $P(S_2) = 1 - P(S_1)$. Let A_1 denote 'yes' and A_2 denote 'no'. The probability of a hit (H), then, is $P(H) = P(A_1/S_1)$, and the probability of a false alarm (F) is $P(F) = P(A_1/S_2)$. The following two-by-two performance matrix summarizes these definitions.

	A_1	A_2
S_1	$P(H)$	$1 - P(H)$
S_2	$P(F)$	$1 - P(F)$

The basic theory of signal detection depends on two processes: an activation process and a decision process. The activation process specifies the relation between external stimulus events and hypothesized sensory states of an S. The decision process specifies the S's response in terms of his sensory state and the information that he has acquired during the course of an experiment.

According to the theory there exists a continuum of possible observations, X, with two probability density functions defined on it: $f_{sn}(x)$ and $f_n(x)$ (Swets, Tanner, and Birdsall, 1961). Each S establishes a criterion, X_c,

on X and follows this decision rule: if $X > X_c$, S makes an A_1 response; if $X < X_c$, S makes an A_2 response.

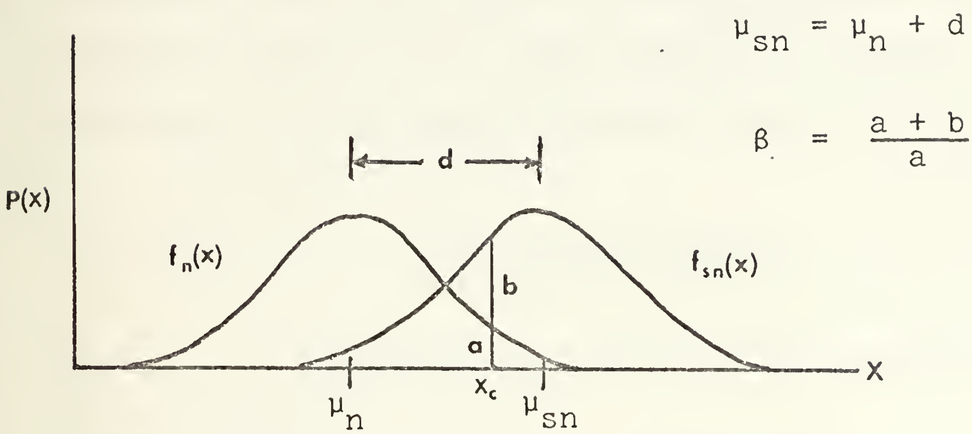


Figure 1: Noise (N) and Signal-plus-Noise (SN) Probability Density Functions

The S establishes the value of X_c on the basis of the likelihood ratio $\beta = \frac{f_{sn}(x)}{f_n(x)}$ (see Figure 1).

Assuming that $\sigma_{sn} = \sigma_n = \sigma$ assures X_c will be unique. Both $f_{sn}(x)$ and $f_n(x)$ are assumed to be normal density functions, and d', defined as $d' = \frac{d}{\sigma}$, is considered to be the sensitivity parameter, which describes the activation process. β is considered to be the bias parameter, which describes the decision process.

In addition to the studies done by Swets, Tanner, and Birdsall on the theory of signal-detection, relevant work includes the treatment of signal detection as a three-state process by Atkinson, Bower, and Crothers (1965), and the identification of bias in signal detection with matching in probability learning by Legge and Thomas (1970).

Atkinson, Bower, and Crothers not only reported considerable evidence directly contradictory to the assumption that every individual is an "ideal observer" (Swets, Tanner, and Birdsall, 1961) who maximizes expected gain whenever he has to make a decision but also presented a formula for bias that includes an individual preference ratio, I. This formula is:

$$B = \frac{P}{P + (1 - P)I}$$

When I = 1, according to this formula, matching occurs since then B = P.

Most response-bias models consider bias to remain constant from trial to trial. Static models with little or no emphasis on dynamic or learning effects have been traditional in psychophysics, even though a response on one trial may be influenced by the stimuli, responses and outcomes of previous trials. These sequential effects have usually been treated as experimental artifacts, to be eliminated by randomization, instructions, or the use of trained subjects.

Taking into account the learning process in a signal-detection task, Atkinson, Bower, and Crothers (1966) developed the preceding formula for asymptotic bias (B), which appears in their three-state model in the following <u>decision</u> matrix:

$$\begin{array}{ccc} & A_1 & A_2 \\ s_0 & B & 1-B \\ s_1 & 1 & 0 \\ s_2 & 0 & 1 \end{array}$$

Pre-multiplication of this matrix by the activation matrix

$$\begin{array}{cccc} & s_0 & s_1 & s_2 \\ S_1 & 1-\sigma & \sigma & 0 \\ S_2 & 1-\sigma & 0 & \sigma \end{array}$$

where σ stands for the sensitivity parameter, produces the performance matrix:

$$\begin{array}{ccc} & A_1 & A_2 \\ S_1 & (1-\sigma)B + \sigma & (1-\sigma)(1-B) \\ S_2 & (1-\sigma)B & (1-\sigma)(1-B) + \sigma \end{array}$$

From the performance matrix, it is possible to relate bias to the proportion of hits P(H) and the proportion of false alarms P(F) in a signal-detection task and thus obtain an estimate of bias, B'.

$P(H)$ is the entry in the S_1 row and A_1 column, and $P(F)$ is the entry in the S_2 row and A_1 column:

$$P(H) = (1-\sigma) + \sigma \qquad (1)$$

$$P(F) = (1-\sigma)B \qquad (2)$$

Using algebraic substitution and solving for σ first from the $P(F)$ and then from the $P(H)$ equation yield:

$$P(F) = (1-\sigma)B$$

$$\sigma = \frac{B - P(F)}{B}$$

and

$$P(H) = (1-\sigma)B + \sigma$$

$$\sigma = \frac{P(H) - B}{1 - B}$$

Equating the two equations for σ and solving for B lead successively to the result:

$$\frac{P(H) - B}{1 - B} = \frac{B - P(F)}{B}$$

$$P(H) = \frac{(1-B)(B-P(F)) + B^2}{B}$$

$$P(H) = \frac{(1-B)(B)-(1-B)(P(F)) + B^2}{B}$$

$$P(H) = \frac{B-B^2-(1-B)(P(F))+B^2}{B}$$

$$P(H) = \frac{B-(1-B)(P(F))}{B}$$

$$P(H)B = B-(1-B)P(F)$$

$$P(H)B = B(1+P(F)) - P(F)$$

$$P(H)B - B(1+P(F)) = - P(F)$$

$$B(P(H) - P(F)-1) = - P(F)$$

$$B = \frac{-P(F)}{P(H) - P(F) - 1}$$

or

$$B' = \frac{P(F)}{1 - P(H) + P(F)}$$

where the prime on the last B shows that it is to be used as an estimator of bias. Similar development of Equations (1) and (2) produces the following relationships between P(H) and P(F):

$$P(H) = \sigma + P(F)$$

and

$$P(H) = 1 - \frac{(1-B)P(F)}{B}$$

These relationships describe the receiver-operating-characteristic (ROC) curves shown in Figures 2 and 3. The curves in Figure 2 are iso-sensitivity curves, and curves in Figure 3 are iso-bias curves. The subscripted letters in these figures indicate curves corresponding to different sensitivities and biases.

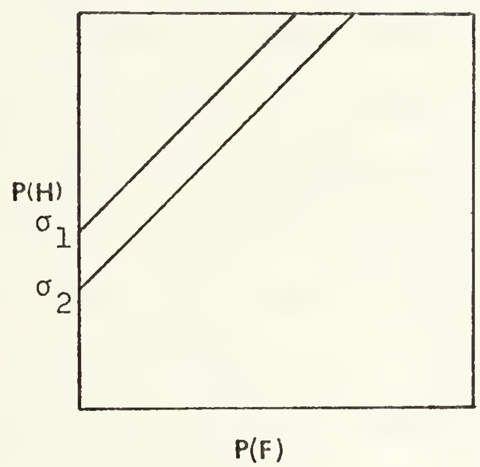


Figure 2: Iso-sensitivity curves

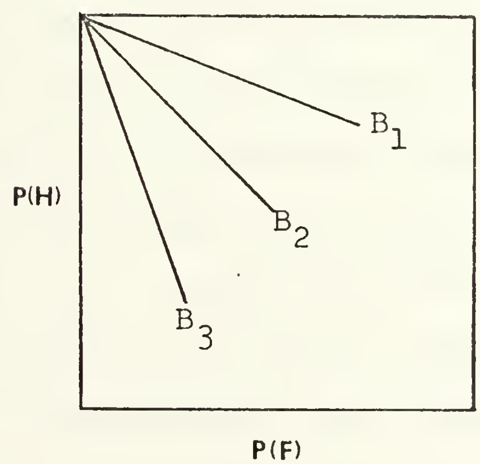


Figure 3: Iso-bias curves

II. EXPERIMENT 1

This experiment consisted of a two-response, visual-detection task. Each S observed from a distance of five feet a slide presentation of a single letter, E or F, displayed on a uniformly illuminated milk-white Plexiglas screen. S was told that the slides shown would be selected at random from a total of 100. When a slide appeared, S had two seconds to respond, by means of a push button, to indicate which letter he thought appeared. With each response, S was given feedback by means of one of two lights, showing whether his choice was correct or incorrect. S was told to respond on each trial regardless of possible uncertainty about which letter appeared.

Prior to the testing period, there was a preliminary test. This test was to determine whether the subject could perform above the probability of guessing. The criterion used permitted the experimenters to be sure with 97.5 per cent confidence that S was above the threshold of completely chance responding. A proportion of choices two standard deviations above the mean was required for S to achieve this criterion. For example, if fifty trials were given, S would have to give at least 31 correct responses. If he did not, the experimenter would adjust the shutter speed till S fulfilled the requirement.

Testing proper consisted of 400 trials which took a total of about 50 minutes, including a 60-second rest period

after each session of 50 trials. Except for the preliminary test, when the shutter speed was adjusted to achieve the criterion described above, the shutter speed remained constant throughout the experiment.

The visual display was an area six inches square, in the center of which one of the upper-case letters, E or F, would appear. The size of the letter remained constant throughout. The experimenters attempted to make the size of the letter equivalent to a 20/20-vision letter on the Snellen chart. However, visual acuity for the shutter speeds used required that the letter be seven millimeters high for viewing at a distance of five feet. This is equivalent to a 20/40-vision letter on the Snellen chart.

S responded to the visual display by pressing one of two buttons set six inches apart on a board that he could adjust to a comfortable position. Punched paper tapes controlled the sequence of letters. The responses were recorded on counters which were electrically wired to a tachistoscope. After the preliminary testing, all responses were recorded for each subject, in the four categories: E/E, F/F, E/F, and F/E.

A. SUBJECTS

The subjects were thirteen military-officer graduate students at the Naval Postgraduate School. Their participation in the experiment required one hour of free time between scheduled classes. None had served in previous

signal-detection studies. Each stated he had 20/20 vision or vision corrected to 20/20.

B. PROCEDURE

Each S was seated in the environmental chamber and received identical instructions explaining the nature of the task. These were the instructions:

> This is a signal-detection task. You will observe on a view screen two upper case letters, an E and an F. Upon seeing an E, respond by pushing the left-hand button. Upon seeing an F, respond by pushing the right-hand button. You must respond on each trial regardless of possible uncertainty about which letter appeared. When you push the button of your choice, push it once and only once. Do not push the buttons prior to a presentation, only after a slide has appeared. You will have two seconds after the presentation to respond. In your field of vision, a set of lights will indicate whether your response was correct or incorrect: green for a correct response; red for an incorrect one. A light will appear immediately upon your response. If, for example, an E is presented and you select an E, a green light will appear. If you select the F and an E is actually presented, a red light will appear. There will be three 100 trials presented during the testing period. They will be divided into sets of 50 trials with a one minute rest period after each set. Prior to the testing period, you will receive 50 to 100 trials to acquaint you with the apparatus and procedures. A single trial will consist of the following time sequence: slide presentation; response time (2.0 seconds); random slide selection and machine cycling (3.2 seconds); followed by next presentation. Inter-communications are provided for any questions you may have during testing. Sound deadening earphones are to be worn in order to prevent noise distraction. When your eyes become night adapted, the testing cycle will start. You will be informed that the testing cycle will commence in two seconds. A presentation will then follow until a set of 50 trials is completed, upon which you will be informed of a one-minute rest period. Are there any questions?

After receiving the instructions, S put on the sound-deadening earphones, the environmental chamber door was closed, and three minutes were provided to allow S to become night-adapted and to test the inter-communication system. The preliminary test, consisting of 50 to 100 trials, followed, and then the main testing began and continued for 300 trials.

C. APPARATUS

In designing the apparatus for the experiment, the concept of no human interference was of prime concern. The entire testing procedure was accomplished electro-mechanically, thus eliminating any human error or bias of the experimenter. The apparatus consisted of five major components: (1) projection chamber; (2) viewing chamber; (3) tachistoscope; (4) environmental chamber; and (5) observation center.

Projection chamber.

The projection chamber was a six-foot aluminum chute, opened at one end. It was designed by the experimenters and constructed by the Naval Postgraduate School Machine Shop using one-sixteenth inch aluminum sheeting. The inside was painted flat black to absorb any light scattering and prevent reflection. The chamber housed a Kodak Ektagraphic RA-960 slide projector. At the opened end of the chute were mounted four light indicators (two green, two red) for feedback; the green lights indicated a hit or correct

rejection (E/E or F/F), and the red lights indicated a miss or false alarm (F/E or E/F).

Viewing chamber

The viewing chamber was a five-foot aluminum chute, opened at both ends. This too was designed by the experimenters and constructed by the Naval Postgraduate School Machine Shop using one sixteenth inch aluminum sheeting. It was painted flat black for the same reason as the projection chamber. Attached to the viewing chamber were two pushbuttons which permitted S to make noise (F) and signal-plus-noise (E) responses respectively.

Tachistoscope

The random-access projection tachistoscope system was designed by the Lafayette Instrument Company. This system incorporates three standard components mounted in a common 21-inch relay rack and inter-connected to provide tachistoscopic projection with complete random-access ability. (a) The 52023 timer allowed for repeat cycling and automatic system operation. (b) The 43016 (VS1-E, tape) provided a trip pulse to the shutter for exposures from $\frac{1}{125\text{-th}}$ to one second. (c) The Digitronic, Inc., tape reader allowed for random access to the projector carosel. This feature made possible random selection of slides by use of the binary - binary-nine system, permitting the presentation of random sequences and varying percentages of the E's and F's.

Attached to the tachistoscope were four response counters. The four counters kept a running account of hits, misses, correct rejections, and false alarms. Appendix F is a wiring diagram of this circuit, which was made compatible to the Lafayette tachistoscope. Also connected to the tachistoscope were four response-feedback light indicators. Immediately upon response, these indicators would inform S whether his choice was correct or incorrect. Green indicated correct, and red, incorrect.

Environmental chamber

The experimenters felt that the conditions of testing were adequate and well-controlled. To assure that the results of the tests would be meaningful and useful, it was considered necessary to control lighting, atmospheric characteristics, distracting noises, and working facilities. The environmental chamber provided optimal control of these conditions. In addition, it contained the viewing chamber, the communication system between observer and experimenter, and a milk-white Plexiglas screen.

Observation control center

The observation control center provided a facility for monitoring of the equipment, S's responses, and intercommunications. In addition, it allowed for control of the environmental conditions throughout testing.

Through the use of an Ektagraphic copier and 304 instamatic camera, the 126-millimeter slides used in the experiment were made by photographing black upper-case E's and F's on

a white background. Careful attention to slide mounting and centering insured consistent positioning of each letter during presentation.

The program which produced the stimulus punch tape was written in basic programming language and executed on the Digital PDP-8 Lab E computer. It was a general program. Within the program, the experimenters set the percentages of E and F controlling digits to be punched.

The Digital machine punches in ASCII (American Standard Computer Code) while the Digitronic, Inc., punch-paper-tape reader reads in binary - binary-nine code. Another program was thus used to transform the ASCII code to binary - binary-nine by using the CDC-160 computer tape reader and punch.

III. EXPERIMENT II

This experiment was the same as Experiment I, with one exception: the shutter speed remained constant at 250 milli-seconds while the size of the upper case letters E and F varied from four mm. to six mm. in the preliminary test in order to make sure that the subject was above the threshold of completely chance responding. The remainder of the experiment proceeded exactly as Experiment I, with the shutter speed fixed at 250 milli-seconds and the letter size as determined in the preliminary test.

A. SUBJECTS

The subjects were six military-officer graduate students at the Naval Postgraduate School. Their participation in this experiment required one hour of free time between scheduled classes. None had served in previous signal-detection studies. Each stated he had 20/20 vision or vision corrected to 20/20.

B. PROCEDURE

The procedure was the same as it was in Experiment I. S's task was made difficult because of the size rather than the duration of the stimulus. For an S with 20/20 vision, the size of the stimulus (E or F) was thus equivalent to the size of a letter on a line below the 20/20 line on the Snellen chart. The actual size of the stimulus, of course, depended on its distance (five feet) from S.

IV. RESULTS

A. PILOT STUDY

The first attempt at conducting the experiment gave the experimenters insight into an important factor which had been previously overlooked. The first seven Ss were given 600 trials with a total running time of 75 minutes. Bias prediction was inaccurate, and graphing the Ss' sensitivity showed in general that sensitivity declined significantly as the experiment progressed. From this data, it was concluded that Ss were showing various degrees of fatigue. To eliminate this problem the number of trials was decreased and a longer rest period was given following each set of trials.

B. RESULTS OF EXPERIMENTS

A summary of the results appears in Appendices A, B, and C. In Appendix A, B_1 is the calculated bias of S for a signal-to-noise ratio of 50/50. B_2 is the estimator of bias for a signal-to-noise ratio of 40/60. B_3-B_2 is the difference in the prediction of bias showing whether the prediction over-or under-shot the predicted values. I is the individual preference ratio, showing that, when $I > 1$, S prefers noise (F) and, when $I < 1$, S prefers signal plus noise (E). The same notation applies in Appendix B and Appendix C.

Comparing the data of Ss in Appendices A, B, and C shows that the best Ss, those having $-.05 < B_3 - B_2 < .05$, had I values that were relatively constant. This indicates that these Ss had reached the asymptotic-performance level which, according to Atkinson, Bower, and Crothers (1965), is a prerequisite for their use of the bias-prediction formula. The first seven Ss had not reached this asymptotic-performance level.

The ROC curves in Appendix D show that the sensitivity parameter for almost all Ss decreased near the completion of the testing. This indicates that fatigue was again a factor which could not be eliminated in these experiments.

A nested-factorial analysis of the individual preference ratios (I) computed from the data shown in Appendices A, B, and C was performed separately for Experiments I and II, and the results appear in Appendix E. In both experiments, the reliability of data proved to be insignificant: $F(6,12) = 1.660$, $\underline{P} > .05$, for Experiment I, and $F(5,10) = 2.694$, $\underline{P} > .05$, for Experiment II. The implication of these results is that differences among individuals showed no greater variation than differences within individuals from one signal-to-noise ratio to another.

V. DISCUSSION

The results of these experiments provided little evidence of the reliability of estimated individual bias parameters. As to the usefulness of estimates of individual bias parameters obtained in one signal-detection task for predicting performance in other signal-detection tasks having different signal-to-noise ratios, both experiments generally provided confirmation.

Letter recognition is a complex problem. While one can draw an analogy between detection experiments using white noise with auditory signals and this study using the letter F for noise, it is possible that the letter F does not have the same effect in visual stimulation as does white noise in auditory stimulation. Neisser (1967) and Posner (1969) point out the complexities of letter-processing. J. E. Smith (1972), moreover, reported that estimated response bias in signal-detection tasks are highly dependent upon the particular model used to obtain the estimate.

It is interesting to note that all Ss had a preference ratio I > 1.0. This means that all Ss had a preference of choosing more noise, F, than signal plus noise, E. Two possibilities exist to explain this phenomenon. The first possibility is that S was looking for an E presentation because of E's position in the alphabet. When he did not see an E or was in doubt, S responded with an F. The

second is that S, when in doubt, tended to pick the simpler F.

Further research in this area could be accomplished by using P for noise and R for signal plus noise, or O for noise and Q for signal plus noise. If the assumption is valid as to alphabetical order, the S now would be looking for a P or O and, when he does not see it, will respond with a R or Q. This would result in a performance ratio of $I < 1.0$.

To obtain stable data, better results, as well as to eliminate fatigue of the Ss, fewer Ss perhaps should be obtained but each S should be required to participate in more periods of testing. These periods of testing would be shorter in duration, thus eliminating fatigue and therefore providing more stable data and better results.

To eliminate the factor of autokinesis or eye strain, a ring generator should be wired to the tachistoscope. This would be connected to sound earphones, thereby providing the Ss with a warning of the next slide presentation. This would allow the S to be prepared and ready, while relieving eye strain and the tendency to blink during a stimulus presentation.

To eliminate eye dilation and irritation due to the slide projector flash, a uniformly lit white screen could be used. This would help keep pupil dilation and eye irritation to a minimum.

APPENDIX A: BIAS PARAMETERS (50/50 to 40/60)

Ss	B_1	B_2	B_3	$(B_3 - B_2)$	I
01	----	----	----	----	----
02	----	----	----	----	----
03	----	----	----	----	----
04	----	----	----	----	----
05	.204	.099	.229	.130	3.889
06	.250	.181	.141	-.040	3.000
07	.097	.067	.153	.086	9.333
08	.326	.243	.267	.024	2.071
09	.250	.182	.175	-.007	3.000
10	.237	.171	.216	.045	3.222
11	.194	.139	.154	.015	4.143
12	.167	.118	.163	.045	5.000
13	.214	.154	.200	.046	3.667
14	.205	.147	.135	-.012	3.875
15	.298	.221	.280	.059	2.357
16	.143	.100	.146	.046	6.000
17	.200	.143	.176	.033	4.000
18	.238	.093	.028	-.065	6.500
19	.139	.084	.125	.041	6.200

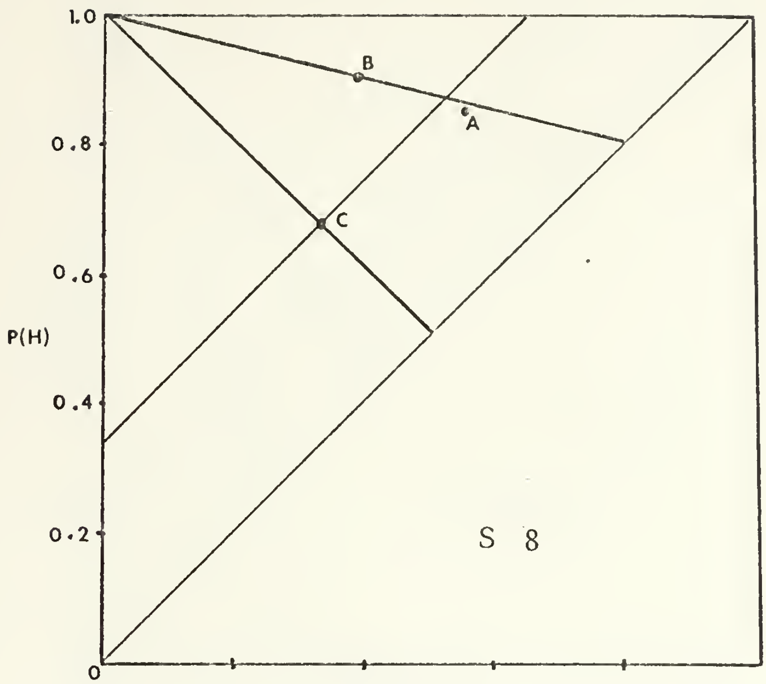
APPENDIX B: BIAS PARAMETERS (40/60 to 30/70)

Ss	B_1	B_2	B_3	(B_3-B_2)	I
01	----	----	----	----	----
02	----	----	----	----	----
03	----	----	----	----	----
04	----	----	----	----	----
05	.229	.161	----	----	2.242
06	.141	.096	.104	.008	4.056
07	.153	.104	.200	.096	3.692
08	.267	.190	.231	.041	1.833
09	.175	.120	.109	-.011	3.143
10	.216	.150	.137	-.013	2.424
11	.154	.105	.136	.031	3.667
12	.163	.114	.192	.078	3.333
13	.200	.138	.180	.042	2.667
14	.135	.089	.136	.047	4.267
15	.280	.200	.211	.011	1.714
16	.146	.100	.119	.019	3.889
17	.176	.121	.167	.046	3.111
18	.028	.018	.120	.102	23.333
19	.125	.084	.128	.044	4.667

APPENDIX C: BIAS PARAMETERS (50/50 to 30/70)

Ss	B_1	B_2	B_3	(B_3-B_2)	I
01	.182	.087	.148	.061	4.500
02	.169	.080	.229	.149	4.929
03	.125	.058	.113	.055	7.000
04	.270	.137	.168	.031	2.708
05	----	----	----	----	-----
06	.250	.125	.104	-.021	3.000
07	.097	.044	.200	.156	9.333
08	.326	.171	.231	.060	2.071
09	.250	.125	.109	-.016	3.000
10	.237	.117	.137	.020	3.222
11	.194	.094	.136	.042	4.143
12	.167	.079	.192	.113	5.000
13	.214	.105	.180	.075	3.667
14	.205	.100	.136	.036	3.875
15	.298	.154	.211	.057	2.357
16	.143	.067	.119	.052	6.000
17	.167	.097	.167	.070	4.000
18	.138	.620	.120	.058	6.500
19	.139	.065	.128	.063	6.200

APPENDIX D: ROC CURVES



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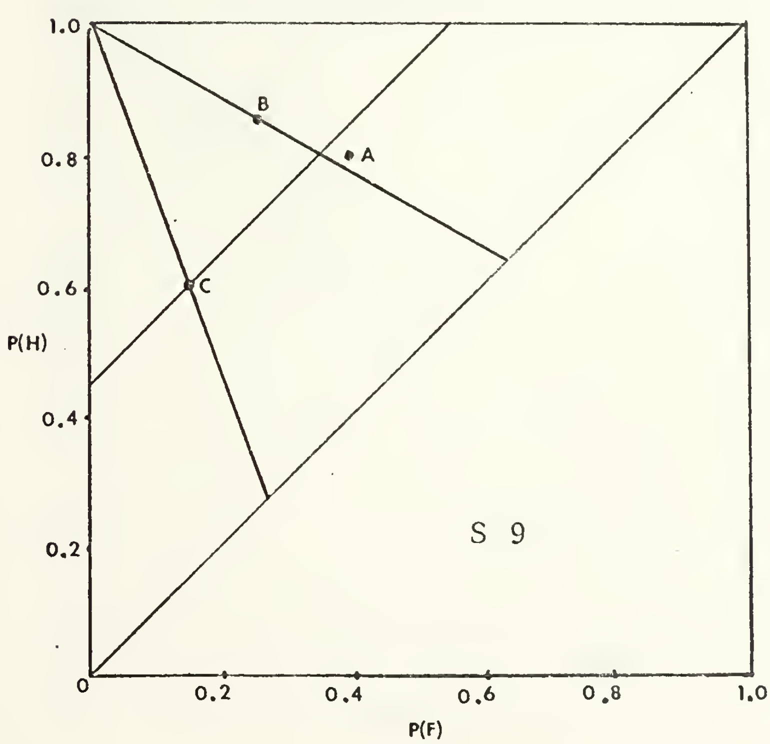
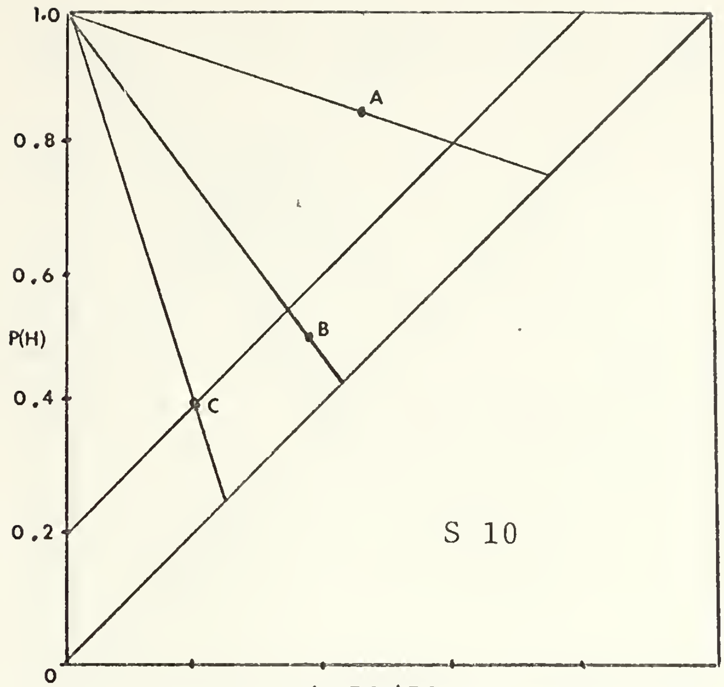
C=30/70





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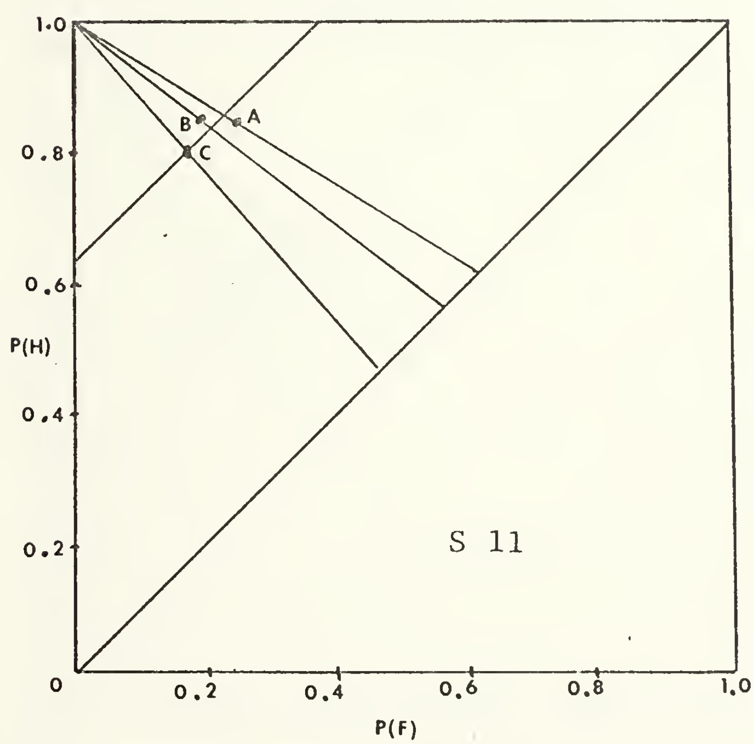

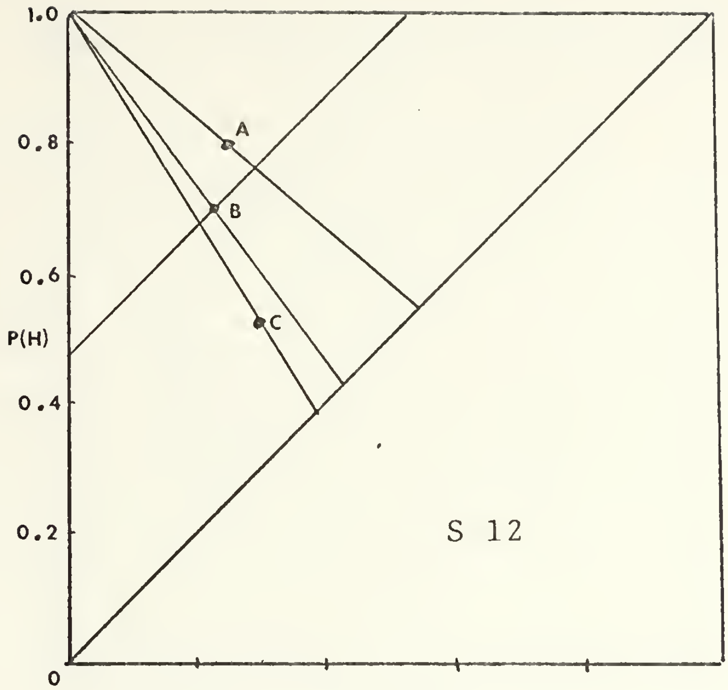

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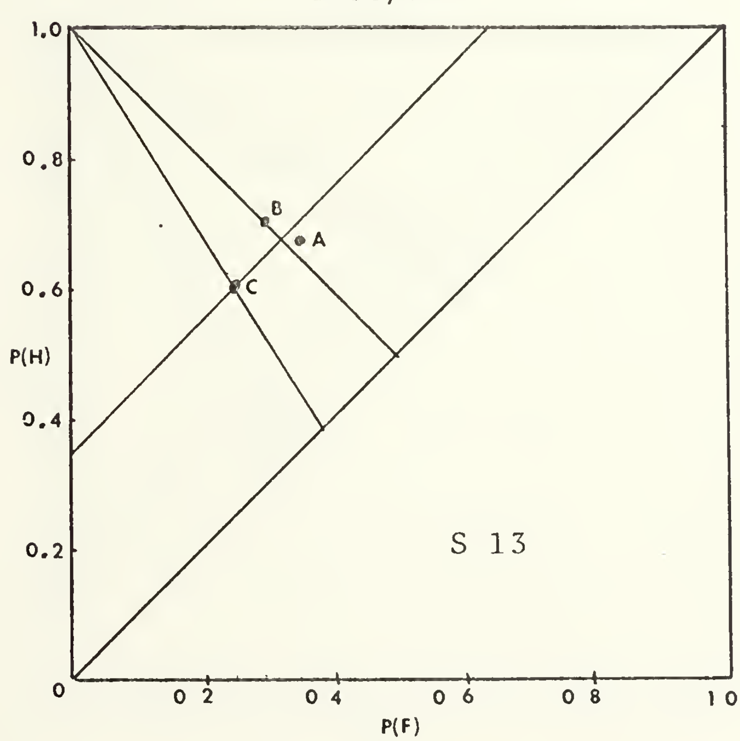

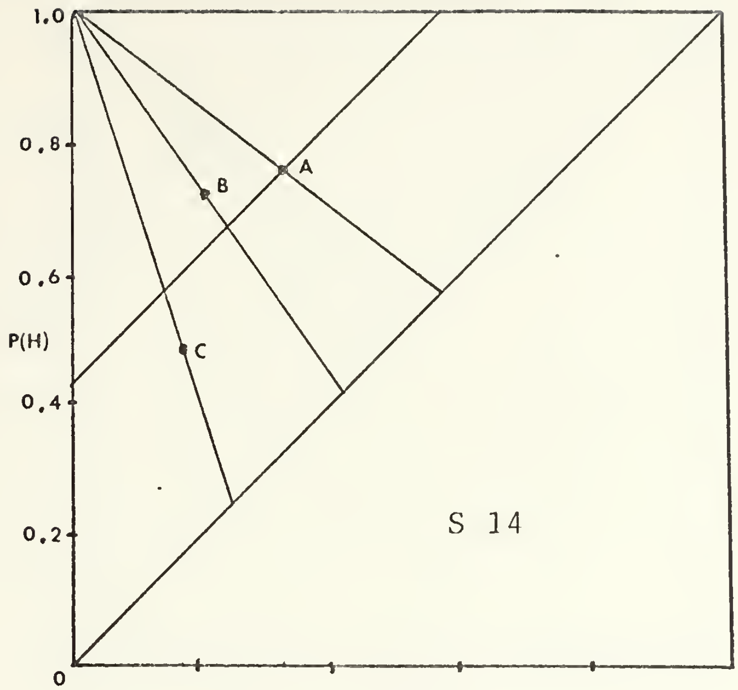

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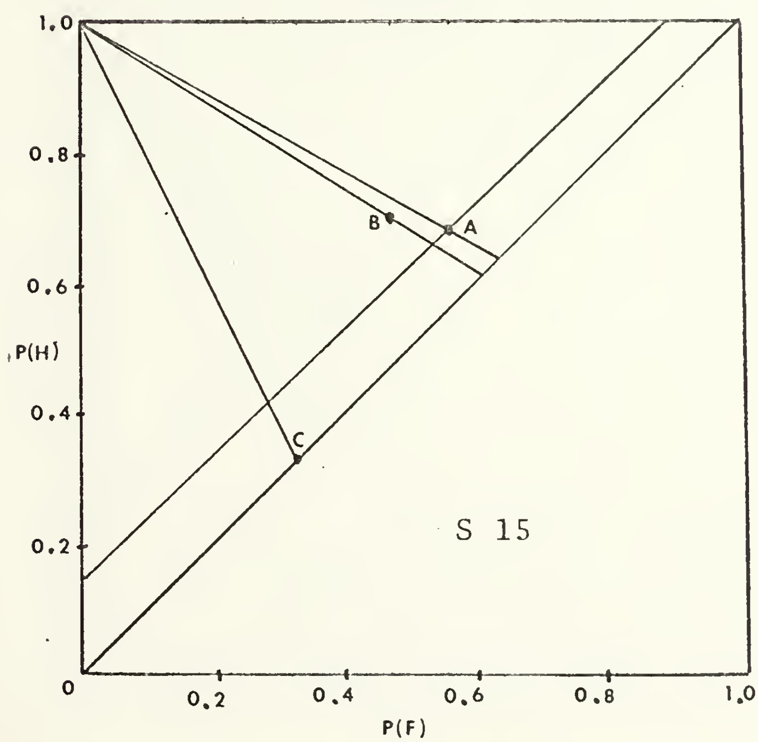

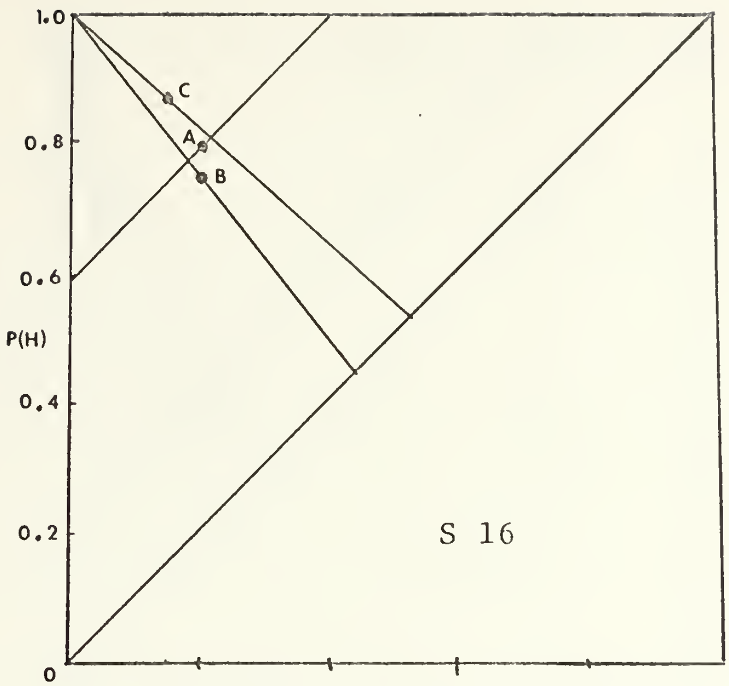

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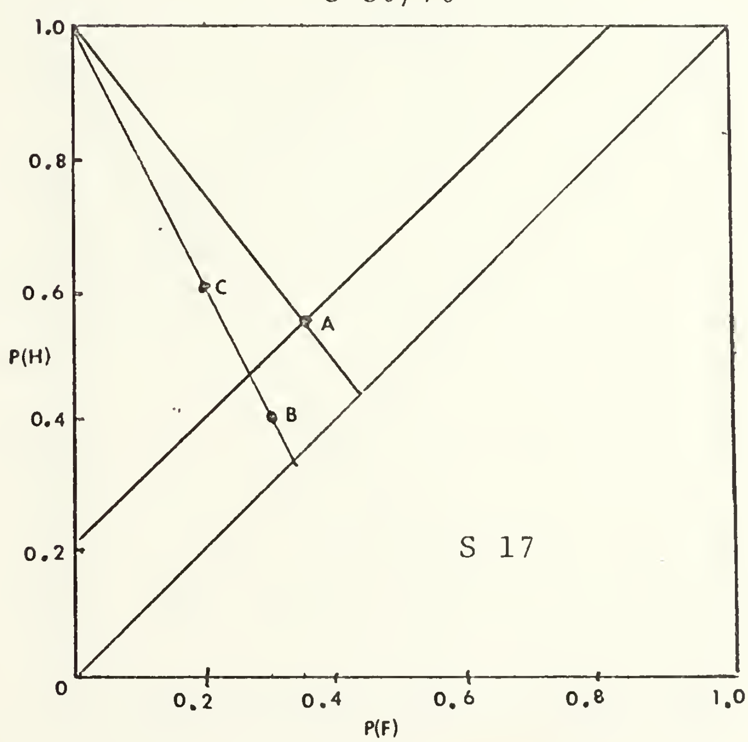

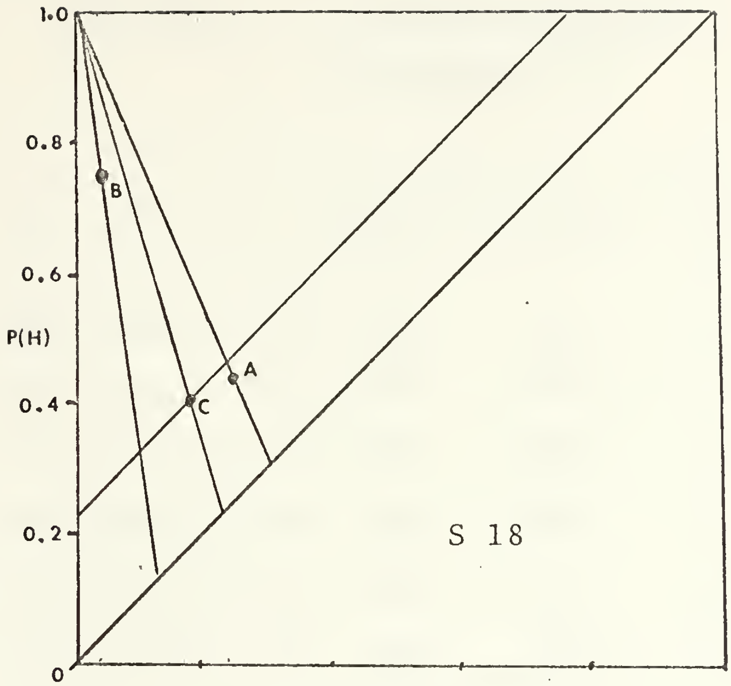

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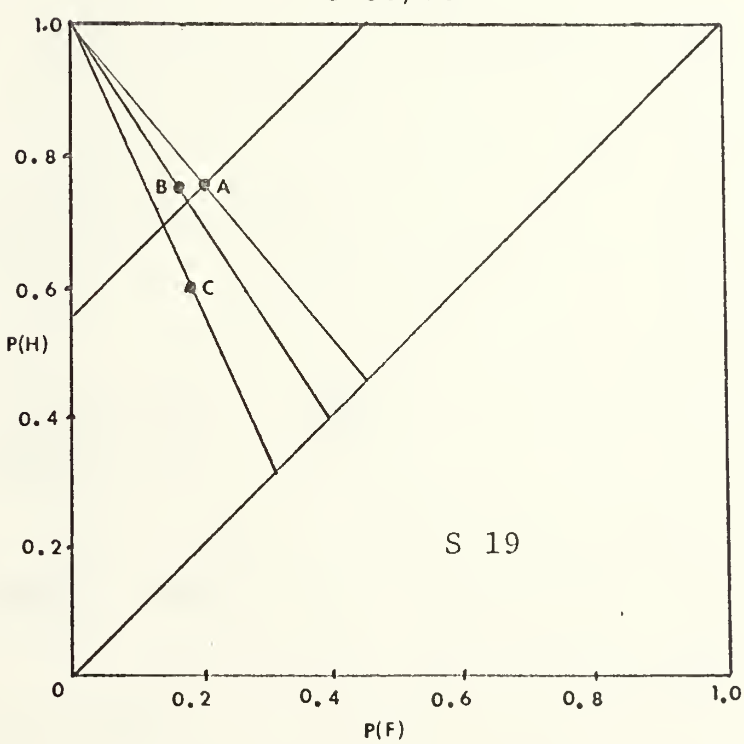


APPENDIX E: FACTORIAL ANALYSIS

(EXPERIMENT 1)

Ss	I_{50}	I_{40}	I_{30}	μ_I	$(\mu_I-\mu_N)^2$	$(I_{50}-\mu_I)^2$	$(I_{40}-\mu_I)^2$	$(I_{30}-\mu_I)^2$
13	3.667	2.667	1.952	2.762	.020	.819	.009	.656
11	4.143	3.667	2.714	3.508	.365	.403	.025	.630
08	2.071	1.833	1.424	1.778	1.268	.086	.003	.122
09	3.000	3.143	3.514	3.219	.099	.048	.006	.087
12	5.000	3.333	1.800	3.378	.225	2.921	.002	2.490
10	3.222	2.424	2.694	2.780	.015	.195	.127	.007
Total				2.904	1.992	4.472	.172	3.992

$K = 3 \quad N = 6$

$$\frac{K \sum_{i=1}^{N} (\mu_i-\mu_N)^2}{N-1} = 1.195$$

$$\frac{\sum_{i=1}^{N} \sum_{j=1}^{K} (I_{ij}-\mu_i)^2}{N(K-1)} = .720$$

$$F = \frac{1.195}{.720} = 1.660$$

$$F_{(.05)} = 3.11$$

APPENDIX E: FACTORIAL ANALYSIS

(EXPERIMENT 2)

Ss	I_{50}	I_{40}	I_{30}	μ_I	$(\mu_I-\mu_N)^2$	$(I_{50}-\mu_I)^2$	$(I_{40}-\mu_I)^2$	$(I_{30}-\mu_I)^2$
19	6.200	4.667	2.930	4.599	1.186	2.563	.068	2.786
16	6.000	3.887	3.171	4.353	.711	2.713	.215	1.397
14	3.875	4.267	2.714	3.619	.012	.066	.420	.819
15	2.357	1.714	1.607	1.893	2.615	.215	.032	.082
17	4.000	3.111	2.143	3.085	.181	.837	.001	.887
Total				3.510	4.705	6.394	.736	5.971

$K = 3 \quad N = 5$

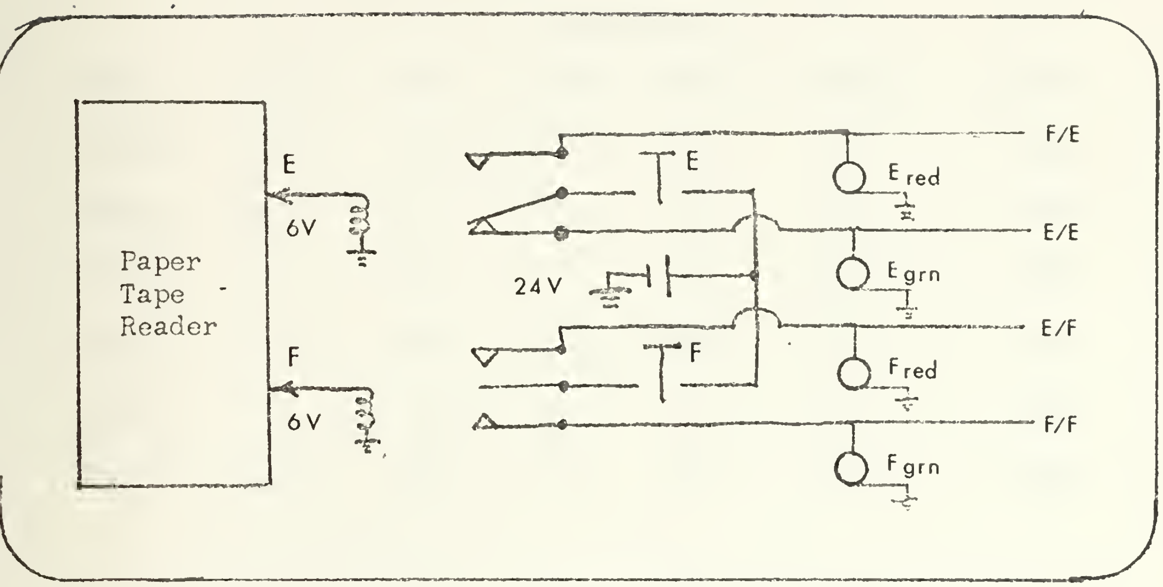
$$\frac{K \sum_{i=1}^{N} (\mu_i - \mu_N)^2}{N-1} = 3.529$$

$$\frac{\sum_{i=1}^{N} \sum_{j=1}^{K} (I_{ij} - \mu_i)^2}{N(K-1)} = 1.310$$

$$F = \frac{3.529}{1.310} = 2.694$$

$$F_{(.05)} = 3.48$$

APPENDIX F: WIRING DIAGRAM



APPENDIX G: RECORDED DATA

Subject 1

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt (mm)
50/50	14	13	11	12	50	033	7
50/50	17	15	08	10	50	067	7
50/50	31	35	19	15	100	067	7
50/50	30	30	20	20	100	067	7
30/70	25	53	05	17	100	067	7
30/70	24	54	06	16	100	067	7

Subject 2

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt (mm)
50/50	20	11	05	14	50	125	7
50/50	33	27	17	23	100	125	7
50/50	31	36	19	14	100	125	7
30/70	24	36	06	34	100	125	7
30/70	16	44	15	25	100	125	7

Subject 3

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt (mm)
50/50	15	18	10	07	50	067	7
50/50	28	34	22	16	100	067	7
50/50	30	40	20	10	100	067	7
30/70	16	54	14	16	100	067	7
30/70	14	59	16	11	100	067	7

Subject 4

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	18	11	07	14	50	067	7
50/50	33	19	17	31	100	067	7
50/50	35	26	15	24	100	067	7
30/70	21	43	09	27	100	067	7
30/70	21	54	09	16	100	067	7

Subject 5

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	15	13	10	12	50	067	7
50/50	13	22	12	03	50	067	7
50/50	30	32	20	18	100	067	7
40/60	26	45	14	15	100	067	7
40/60	26	38	14	22	100	067	7
30/70	18	44	12	26	100	067	7
30/70	--	--	--	--	---	---	-

Subject 6

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	18	13	07	12	50	067	7
50/50	38	33	11	18	100	067	7
50/50	37	30	12	21	100	033	7
40/60	26	44	14	16	100	033	7
40/60	27	48	13	12	100	033	7
30/70	16	61	14	09	100	033	7
30/70	14	60	16	10	100	033	7

Subject 7

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	15	17	10	08	50	067	7
50/50	24	17	01	08	50	067	7
50/50	19	20	06	06	50	033	7
50/50	44	44	06	06	100	033	7
40/60	30	40	10	20	100	033	7
40/60	28	47	12	13	100	033	7
30/70	17	42	13	28	100	033	7
30/70	16	49	14	21	100	033	7

Subject 8

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	20	09	05	16	50	125	7
50/50	15	05	10	20	50	125	7
50/50	23	15	02	10	50	125	7
50/50	21	11	04	14	50	125	7
40/60	17	19	03	11	50	125	7
40/60	17	18	03	12	50	125	7
30/70	09	16	06	19	50	125	7
30/70	10	23	05	12	50	125	7

Subject 9

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	13	14	12	11	50	067	7
50/50	10	13	15	12	50	067	7
50/50	17	15	08	10	50	125	7
50/50	20	15	05	10	50	125	7
40/60	16	20	04	10	50	125	7
40/60	17	23	03	07	50	125	7
30/70	05	27	10	08	50	125	7
30/70	09	30	06	05	50	125	7

Subject 10

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	18	13	07	12	50	067	7
50/50	17	15	08	10	50	067	7
50/50	18	17	07	08	50	067	7
50/50	21	16	04	09	50	067	7
40/60	11	21	09	09	50	067	7
40/60	10	19	10	11	50	067	7
30/70	07	26	08	09	50	067	7
30/70	06	28	09	07	50	067	7

Subject 11

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	24	25	01	00	50	067	7
50/50	24	21	01	04	50	033	7
50/50	18	18	07	07	50	017	7
50/50	21	18	04	07	50	017	7
40/60	16	22	04	08	50	017	7
40/60	17	24	03	06	50	017	7
30/70	10	26	05	09	50	017	7
30/70	12	29	03	06	50	017	7

Subject 12

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	20	22	05	03	50	067	7
50/50	19	18	06	07	50	067	7
50/50	19	20	06	05	50	033	7
50/50	20	19	05	06	50	033	7
40/60	11	25	09	05	50	033	7
40/60	14	23	06	07	50	033	7
30/70	10	26	05	09	50	033	7
30/70	08	25	07	10	50	033	7

Subject 13

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	14	13	11	12	50	067	7
50/50	21	08	04	17	50	067	7
50/50	12	18	13	07	50	067	7
50/50	17	16	08	09	50	067	7
40/60	13	20	07	10	50	067	7
40/60	14	21	06	09	50	067	7
30/70	10	23	05	12	50	067	7
30/70	09	26	06	09	50	067	7

Subject 14

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	14	13	11	12	50	250	4
50/50	10	12	15	13	50	250	4
50/50	22	17	03	08	50	250	5
50/50	19	17	06	08	50	250	5
40/60	17	23	03	07	50	250	5
40/60	18	25	02	05	50	250	5
30/70	13	25	02	10	50	250	5
30/70	12	29	03	06	50	250	5

Subject 15

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	14	13	11	12	50	250	5
50/50	13	13	12	12	50	250	5
50/50	18	12	07	13	50	250	5
50/50	17	11	08	14	50	250	5
40/60	13	15	07	15	50	250	5
40/60	14	16	06	14	50	250	5
30/70	03	28	12	07	50	250	5
30/70	05	23	10	12	50	250	5

Subject 16

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	09	12	16	13	50	250	4
50/50	23	22	02	03	50	250	6
50/50	17	15	08	10	50	250	5
50/50	20	20	05	05	50	250	5
40/60	17	23	03	07	50	250	5
40/60	15	24	05	06	50	250	5
30/70	10	32	05	03	50	250	5
30/70	13	30	02	05	50	250	5

Subject 17

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	16	22	08	04	50	250	5
50/50	21	24	04	02	50	250	5
50/50	10	18	14	08	50	250	4
50/50	14	16	11	09	50	250	4
40/60	14	19	05	12	50	250	4
40/60	08	21	12	09	50	250	4
30/70	10	25	05	10	50	250	4
30/70	09	28	06	07	50	250	4

Subject 18

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	08	18	17	07	50	250	5
50/50	16	10	09	15	50	250	5
50/50	10	21	14	05	50	250	4
50/50	11	19	14	06	50	250	4
40/60	17	23	07	03	50	250	4
40/60	15	29	05	01	50	250	4
30/70	06	30	09	05	50	250	4
30/70	06	29	09	06	50	250	4

Subject 19

Ratio	E/E	F/F	F/E	E/F	Trials	mSec	Hgt(mm)
50/50	14	12	11	13	50	250	4
50/50	15	09	10	16	50	250	4
50/50	20	20	05	05	50	250	5
50/50	19	20	06	05	50	250	5
40/60	18	24	02	06	50	250	5
40/60	15	25	05	05	50	250	5
30/70	10	28	05	06	50	250	5
30/70	09	29	06	06	50	250	5

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STRACT

The performance of an individual in a signal-detection task depends on two
ependent psychological processes. One of these processes is sensory activation,
the other is cognitive decision. In a signal-detection experiment, a subject
t decide whether a signal is present in a background of noise. When detection
not easy, the subject often shows bias. This thesis reports a signal-detection
eriment that was performed (a) to determine the reliability of estimated
ividual bias parameters in a number of signal-detection tasks and (b) to evaluate
usefulness of estimates of individual bias parameters obtained in one signal-
ection task for predicting performance in other signal-detection tasks having
ferent signal-to-noise ratios. The signal-detection tasks required identification
two upper-case letters of the alphabet presented for brief fixed-time intervals.
letters were F (noise) and E (signal plus noise). Nineteen subjects
ticipated in the experiment. The results supported hypothesis (a) inasmuch as
imates of individual bias parameters tended to be reliable. Performance
diction from one signal-detection task to another generally provided
firmation of hypothesis (b) as well. The support for neither hypothesis was
y strong, however, and the thesis concludes with a number of suggestions for
ther research.

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KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
signal detection performance						
visual acuity						

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